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Original research article

Reimagining net metering: A polycentric model for equitable solar adoption in the United States

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ABSTRACT

Disparities in renewable energy deployment disproportionately afflict marginalized communities and slow the clean energy transition necessary to combat climate change. Most solutions focus on top-down government initiatives to subsidize renewable energy. However, this approach has had mixed efficacy, raises questions about the durability of support, and lacks political feasibility in certain contexts. We propose a new energy development model that leverages the logic of polycentric governance, which refers to having multiple centers of decision-making as opposed to one. Our model rethinks the practice of net metering, where households and organizations can sell excess power back to the grid. Rather than pocketing the proceeds, our model taps into individual altruism by allowing households and organizations to donate some of this money to build renewable energy for underserved communities. This could accelerate clean energy development by providing resources and fostering collaboration between communities and power companies. Our framework represents a novel decentralized approach to a "just energy transition" that complements government-led initiatives. This paper describes the program, discusses design issues, and presents proof-of-concept survey research from the United States.

1. Introduction

The clean energy transition promises to mitigate the worst impacts of climate change and, with the right policies, rectify disparities in renewable energy deployment [1]. Solar power, in particular, provides a scalable way to generate affordable, clean energy for homes, businesses, and communities. While rooftop solar has grown by 50% annually over the last decade, the gains from this development have been unequal. After accounting for income, Black- and Hispanic-majority areas in the United States have 69% and 30% less solar installed on average than other communities [2]. Households at low and moderate income levels are four times less likely to install rooftop solar compared to those with higher incomes [3].

These disparities present a significant public policy challenge and raise moral questions about the allocation of resources. From the climatic perspective, the uneven adoption of solar slows the pace of the clean energy transition, which must move quickly to meet emissions targets [4].

From an equity perspective, the lack of affordable, clean energy reinforces inequalities. More than one in four American families regularly struggle to pay energy bills or sustain adequate heating and cooling in their homes [5,6]. This leads people to take risks such as incurring debt or spending less on essential goods like medicine—and have their power disconnected in the extreme [7,8].

The reasons for disparities in solar adoption are complex. Previous studies point to cost barriers and informational deficits, compounded by systematic inequalities such as geographic income segregation [2,9,10]. Low-income households are also more likely to be renters, so they face additional constraints on solar investments [11,12]. Policy responses to these inequities have often emphasized top-down government solutions like subsidies.

However, there are three reasons why a new energy development model should move beyond the top-down approach. First, government efforts to reduce the costs of solar adoption with subsidies like up-front

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rebates have been met with limited success [3,13–15].[3] This is unsurprising given studies about how some problems are best solved by having multiple decision-makers at different levels [16], what Ostrom [17] calls "polycentric" governance. Second, government subsidies confront credible commitment problems that can lead to suboptimal levels of investment since firms fear political and economic conditions might change in the future [18,19]. Lastly, the top-down approach assumes political will exists to enact such a policy, which is not always the case in the United States and globally. A ground-up model is needed to complement top-down efforts where they exist and as a strategy to spur the energy transition in places where governments have taken little action.

Our main contribution is to propose and test a proof-of-concept for a ground-up model of renewable energy development. Our model takes advantage of the rapid growth of solar generation by commercial, industrial, and residential users (Figure A1), and is inspired by the call for a "moral political economy" [20]. We reimagine the practice of net metering, proposing that households and organizations earning solar revenue can make donations to install solar for energy-poor communities. Our model combines independent efforts to install free-of-charge renewable energy in low-income communities (e.g., GRID Alternatives) with efforts to channel household net metering proceeds to pay the electric bills of low-income consumers (e.g., Resonant Energy's Solar Equity Program). To our knowledge, this is a novel proposal, at least in the scholarly literature. We are also the first to analyze the constraints such a program would face, design decisions, and the attendant trade-offs.

Our decentralized model complements government-led programs such as those to offset installation costs. For example, the Inflation Reduction Act (IRA) in the United States contains incentives for low-income households to install renewable energy and other cost-saving, climate-improving technologies. Our model leveraging net-metering donations could be coupled with these incentives, perhaps leading to additional tax advantages for donors, a proposal we evaluate empirically.

Our article presents the results from a series of empirical tests evaluating how the program could be designed to garner participation. We fielded two national surveys of the American population (total $N = 2893$). The surveys assessed whether the public would participate. If so, who would be most interested in participating, and how much would they donate? We also embedded a conjoint experiment to measure preferences over the design of the program. Our analysis builds on earlier work on citizen preferences over energy policies by examining how new program designs could chart a path toward a more just energy system by unlocking the energy of households and organizations [e.g., 21].

We report five primary findings that indicate our program holds great potential. First, a majority of Americans (60%) would be willing to participate in our proposed program. Of those interested in purchasing solar, they would donate 38% of their net-metering proceeds to help build out solar in communities facing energy poverty.

Second, the design of the program influences the level of public support and the size of donations. People care foremost about targeting the funds to help low-income communities as opposed to making the funds universally available. Further, we find that top-down initiatives like subsidies complement, rather than crowd out, bottom-up efforts.

Third, polycentric governance improves the perceived effectiveness of the program. When power companies implement the program in tandem with the state government and local communities, citizens say they are more likely to participate than when the government acts alone. Expectations that the program would succeed at alleviating energy poverty also increase as a consequence of polycentric decision-making.

Fourth, it is possible to design the program to minimize potential barriers to participation, such as loss aversion. An intervention that ensured participants did not anticipate being in the domain of losses increased the amount they were willing to donate, boosted rates of intended participation, the propensity to seek and share information about the program and support for power companies providing a donation option.

Lastly, we find that our proposed program should be in the interest of power companies to adopt. Our survey experiments show that if utilities participated in our model, they would dramatically improve their public image in the communities they serve. This matters since the model's implementation will depend on factors beyond public will, such as state policies and power company collaboration, which have confronted political and technical challenges [22,23]. Our model could garner power company participation through their incentives to build goodwill and fulfill their stated commitments to reduce energy poverty and achieve climate goals.

In what follows, we describe the model in greater detail and discuss program design considerations. Then we present survey evidence on whether individuals would participate in such a program and their preferences over its design. Lastly, we lay out our plans for follow-up studies.

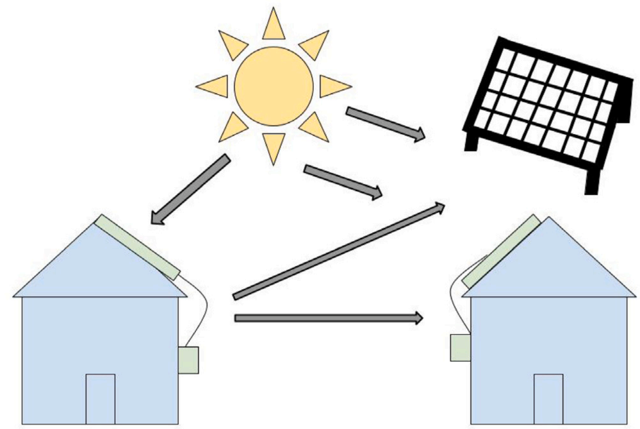

Fig. 1. Ground-up energy development model illustration. Funds raised by one household can be donated to install residential and community solar projects.

2. A new ground-up model of energy development

Our model takes advantage of the fact that households and organizations with solar panels can generate excess energy. Some states allow for this energy to be sold back to the electrical grid, a practice known as net metering. How this transaction happens varies, but there is no logical constraint in principle on how this money could be used. Currently, people tend to pocket these savings to pay back the costs of installation and generate additional income.

We reimagine the possibilities of net metering by asking, what if households could do something else with the money generated by their excess energy? What if they could donate that money to help build renewable energy to power communities facing energy poverty?

Seen in this new light, the proceeds from clean energy surplus go into creating more renewable energy capacity elsewhere. In turn, these investments help reduce greenhouse gas emissions in other communities while simultaneously addressing energy insecurity. Fig. 1 illustrates our model of energy development. To our knowledge, this model has yet to be discussed or studied. Our proposal taps into altruistic motivations by providing opportunities for individuals and organizations to reduce inequality and planet-warming emissions. In turn, this should enhance the durability of decarbonization by creating interests with a stake in the energy transition, harnessing human energy yet to be tapped.

There are piecemeal examples that demonstrate the feasibility of our model. In Massachusetts, customers with solar panels can submit

[3] O'Shaughnessy et al. [3] review other solutions that include leasing and informational campaigns.

a 6-page Schedule Z form, which is the required paperwork to transfer a customer's net metering credits to another account with the same electric company in the same load zone.[4] This is not a donation of *electrons* from one home to another but a transfer of *credits* to pay for a bill. In contrast, our approach examines how net-metering credits could be used to fund renewable energy projects rather than offset individual bills. Our model supplies targeted communities with perpetual free, clean energy.

While solar installation entails upfront costs, economic assessments indicate that households and organizations should have savings due to lower electricity bills and net metering proceeds from which they could make donations [24–26]. Wealthier households may make one-time installation payments, whereas others take out loans. Regardless of the financing structure, these studies suggest that the average household with solar has monthly savings that could be allocated to cover installation costs or make donations as we propose. As the costs of solar continue to fall with technological advancements and government subsidies, households and organizations should have even greater capacity to make donations.

Three features of our proposed model help to address installation costs. First, the pool of potential donors with rooftop solar tends to face a weaker budget constraint because they have already paid down all or part of their installation costs and are often wealthier. Second, the motivation for the program is that it would cover installation costs in the target communities, thereby freeing up their net metering proceeds to make further donations. Third, the polycentric approach mixes levels of governance, so federal and state tax incentives defray installation costs and further the effectiveness of the donation program, a claim we test empirically.

2.1. Tapping into individual altruism

Our model leverages the altruistic motives of people to reduce inequality.[5] These motives may be prevalent in the potential donor pool of people with solar because factors encouraging solar development, like environmental concern, often correlate with caring for the well-being of people other than oneself [28,29]. Altruistic motives are also present in the general public. Many individuals want to help marginalized communities, evidenced by considerable charitable giving [30], including in the climate domain [31]. Indeed, a range of studies document how certain people have a preference for fairness, a phenomenon termed "inequity aversion" [32–34].

Energy poverty is a clear injustice that should capture the attention of inequity-averse individuals. Our model taps into these altruistic motivations, providing a way for households and organizations to directly address energy poverty while driving down planet-warming emissions. Beyond households, organizations with physical headquarters, like businesses and community centers, could also install solar panels that generate net metering proceeds that could be donated.

2.2. The polycentric advantage

Our model departs from the focus on top-down government initiatives to tap into decentralized decisions that individuals and organizations can make. These decisions do not occur in a vacuum. They happen within local contexts with a variety of stakeholders and governance structures: individual property owners seeking to donate net-metering proceeds, communities aiming to benefit from donations, utility companies maintaining a broader energy infrastructure, regional energy regulators seeking stability, and multiple levels of government negotiating with competing stakeholders.

It is in contexts like these that polycentric governance holds considerable promise. The idea of polycentric governance emerged with the study of public service provision, which Ostrom [35] has extended to study common pool resource problems more generally. We focus on polycentric governance with respect to mixing multiple levels of action and mechanisms rather than considering top-down solutions as the only approach [36].

A growing literature highlights the applicability of polycentric governance to energy research [37–39]. For example, Sovacool [37] describes polycentric approaches to climate and energy governance, with a focus on the mixing of local, national, and global scales; mechanisms such as tax credits and ground-up action; and actors such as regulators, businesses, andindividuals. Shaviv et al. [40, 1] note how distributed energy systems like rooftop solar are upending "traditional hierarchical" business models to include "new actors". In fact, an example of polycentric governance given by Ostrom [36, 357] is household investments in solar.

Building on this theory, we expect that our program's ground-up process of decision-making should make it more successful in addressing energy poverty and climate change. Incorporating multiple levels of governance should increase willingness to participate in the program, increase expectations that the program will succeed, and foster trust between the different levels (e.g., property owners, power companies, and government officials). With this foundation, we next discuss crucial design considerations.

2.3. Program design

2.3.1. Eligibility

The first program design decision is to define the individuals and communities eligible to receive donations. A starting point would be to use studies that document inequities in solar adoption to provide data-driven tools identifying where gaps exist [2]. There would have to be a certification of eligibility, which is standard for programs by power companies and governments providing subsidized electricity, such as the Low Income Home Energy Assistance Program (LIHEAP). There should be input from affected communities when defining eligibility to incorporate their knowledge and expertise.

2.3.2. Investment choice

The next implementation decision is how the donated funds should be invested. There is an ever-expanding array of solar investment options. Rooftop solar is one approach. Property owners or collectives could access a general fund supported by donations. Renters could encourage their landlords to do so or organize their neighbors to back community solar projects. Local institutions, such as schools and places of worship, might also be interested.

Investments could also go to "community" solar projects, which entail constructing larger installations that serve a range of consumers within a geographic area. This approach takes advantage of economies of scale from installing and maintaining more panels in a single location that might also be better exposed to sunlight. Community solar projects could also help to side-step construction barriers from housing stock quality or the barriers that renters face. Communities with infrastructure or space limitations could also make alternative investments in utility-scale solar that subsidize local power via credits.

Research on polycentric governance indicates that involving community members, such as via formal advisory councils, will be crucial for directing funds. Local participation can serve to identify areas of investment within target communities and foster trust between all parties. The academic and practitioner literatures cited above make this point frequently in contexts similar to this paper's proposed model.

2.3.3. Incentives for donor participation

The program will have to consider how its design influences incentives for donor participation. Some households and organizations

[4] In our informal conversations, few are aware of this program. Processes like this also appear burdensome, which has led such firms as Resonant Energy to create software minimizing the administrative burden.

[5] People may also donate for selfish reasons like prestige or a "warm glow" [27].

will be enthusiastic participants, while others will be more reluctant. Factors like income, energy use, amount of net metering, and ideology might influence decisions to adopt solar. How the program's design interacts with these factors will matter for encouraging, sustaining, and expanding participation.

The first step to understanding incentives to participate is to identify potential barriers. We consider three obstacles and how they might be solved using solutions from behavioral science.

Obstacle 1: Loss aversion. If a household expects it could end up paying money for its overall electricity usage after accounting for donations, this could dampen participation. This may be important because renewable energy generation and consumption vary over time. If in one month, households end up paying for energy—or *expect* to pay—this could decrease participation due to loss aversion operating via expectations about the future [41].

Consequently, policy designs should protect donors from being in the domain of losses, which refers to the fear of paying more for electricity than they earn. One way to counteract loss aversion, which we explore later, is to only allow donations if a sufficient "bank" of credits has accumulated to protect against losses.

Obstacle 2: Sludge. Administrative complexity could stifle participation [42], but the program could be designed to avoid these barriers with simplicity and smart defaults [43]. Once set up, donors should have to do little to make adjustments unless they want to, in which case it should be straightforward. Easy-to-use computer interfaces to enroll and manage participation should help.

Obstacle 3: Cost. Tax advantages should also improve participation by reducing cost barriers [44]. Donations could count as charitable contributions on a tax-advantaged basis. Power companies, governments, or other philanthropic organizations, seeing the program as an opportunity to address inequality, could provide "matching" funds that amplify the impact of individual donations. Organizations like National Public Radio already use these techniques to encourage participation.

Additional strategies. Beyond solutions to loss aversion, sludge, and cost, there are other program designs to encourage participation. Studies show how information about neighbor participation [45,46] or setting goals [47] can encourage environmentally beneficial activities. Thus, as more people participate, there should be a reinforcing effect through peer pressure to sign up. Free riding concerns could also be salient, but peer effects can counter-act these pressures [48].

2.3.4. Power company incentives to participate

The program should be designed so power companies see it in their interest to participate. Under standard net-metering regimes, power companies pay households that produce excess energy with cash or credits. Under our model, households would have the option to allocate part of this surplus to build renewable energy. While some power companies oppose net metering, they may be indifferent between allowing donations versus consumers getting checks or credits. Indeed, many companies—at least on paper—have committed to reducing energy insecurity and greenhouse gas emissions. Support for our program would be a litmus test for the credibility of power company commitments.

Program administrators should also evaluate general equilibrium outcomes, accounting for the ultimate balance of supply and demand for solar, to ensure the program does not inadvertently lead to adverse outcomes. One potential general equilibrium effect would be if the proposed model leads firms that already subsidize energy costs for low-income consumers to cut their support for current programs, which could offset the program's gains. However, we do not think this particular outcome is likely because the federal government already funds many subsidy programs and there are reputational constraints on power companies. Another possibility is that increased demand for solar products and services could drive up overall costs. While possible, this seems inevitable if there is rapid growth of renewable energy for decarbonization.

Finally, power companies sometimes raise questions about the demands of solar on the energy distribution infrastructure, which net metering payouts may only partially capture [49]. There is a debate about how and whether to allow utilities to recoup these expenses. These policy and engineering mechanics are beyond our scope.

2.3.5. Beyond solar

We examine our general model in the context of solar. It would be straightforward to have donations support investments beyond solar such as efficient heating and cooling systems (e.g., heat pumps) and electric vehicle charging stations [50]. There are also other forms of renewable energy, like community geothermal. Local considerations like renewable energy suitability could guide these decisions. The clean energy transition will require a multitude of investments that our model could facilitate.

3. Evaluating program design with surveys

3.1. Participation

We fielded a nationally representative survey ($N = 887$) of American adults to learn whether the public would participate in our program and how much they would donate. The survey was part of the Cooperative Election Study conducted in the fall of 2022 over the Internet by YouGov using the firm's matched random sample methodology. The sampling frame employs a six-way cross-classification of age, gender, race, education, region, and sample source. After collection, sample weights adjust for any remaining imbalances.

We asked two questions to measure willingness to participate. The first item asked how much one agrees with the statement: "I would pay higher utility bills if the money went to supporting solar panel projects in my community that would reduce energy costs for low-income residents". Telling respondents they would have to pay higher utility bills makes the scenario more costly, which helps to mitigate potential hypothetical bias when questions do not mention raised costs. This question may overstate the costs since, with net metering, customers would experience lower utility bills. The question also does not include any of the strategies we explore later, so this is a lower bound on willingness to participate.

The second set of questions asked how one would allocate money from net metering. It could be the case that people care most about defraying installation costs and would not donate. So, it is necessary to establish that people would contribute if provided the opportunity.

> Consider that you own a home with solar panels that creates $20 of extra energy each month. You can choose to keep all, some, or none of this money for yourself or donate all, some, or none of this money to programs that reduce energy costs for low-income communities by installing and maintaining solar panels in those communities. How would you allocate $20 a month earned from your solar panels? How much would you keep and how much would you donate?

Respondents indicated how much they would keep or donate, with the total summing to $20. Since this question did not describe any policies to ensure the program delivers credible local benefits, it should underestimate willingness to donate, which should be higher if people anticipated their contributions would be more effectively spent [18].

The question framed the net metering proceeds as extra monthly income, so survey-takers would not assume that they had paid off their solar panels. Their allocation decision would be made in the context of the installation costs they incurred. Indeed, in a follow-up national survey, we asked an open-ended question about the thoughts people had when considering our program, and costs were top-of-mind (Appendix E).

Since there is the possibility of social desirability bias, where people feel pressure to portray themselves as altruistic, we also devised a question asking how much one expected her neighbors to donate. The neighbor version of the question reduces potential stigma from giving answers outside of societal expectations [51].

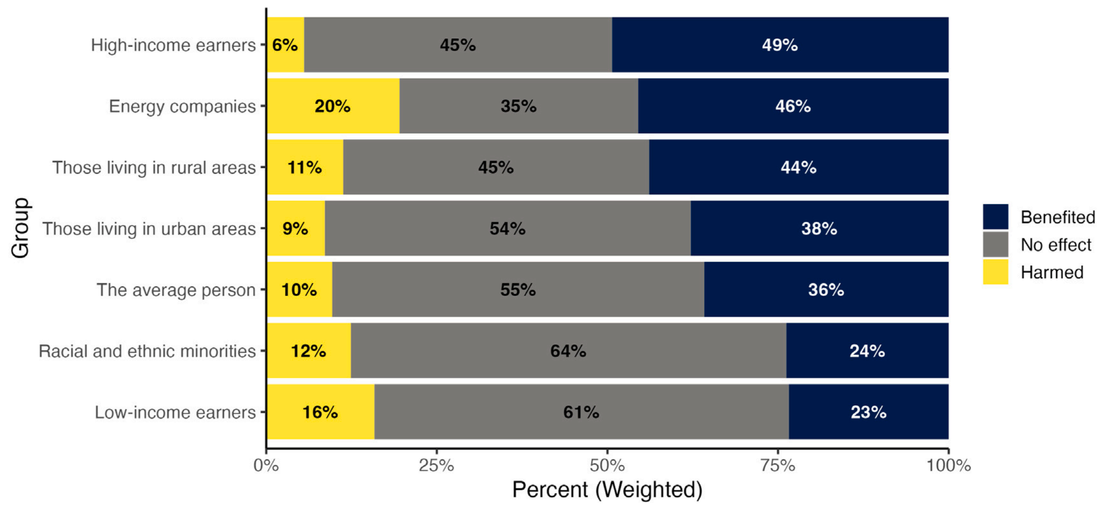

Fig. 2. American public's beliefs about which societal groups have benefited or been harmed by solar deployment. Nationally representative survey ($N = 887$).

3.1.1. Correlates of donation amount

Our discussion about participation incentives implies hypotheses about who should be more likely to donate. First, there should be a positive association between the desire to have a positive impact on the environment and the size of one's donations. We proxy for environmental concern using measures for a respondent's interest in solar installation and an index of climate change concern (Appendix B.1 contains details). We measured interest in solar by asking if the respondent already had or is considering solar for their home. The index for climate change concern consists of six questions about support or opposition to emissions mitigation policies.

Second, studies on inequity aversion suggest that people who recognize the unequal adoption of solar should make larger donations [52]. Our survey question testing this hypothesis asked, "To what extent do you think high-income earners have benefited from the expansion of solar panels for electricity?" The responses range from "harmed a lot" to "benefited a lot".

Since these hypothesized predictors of donations are closely connected with political identities like partisanship, our empirical models also include controls for the respondents' political, social, and economic backgrounds. We treat this analysis as a necessary descriptive step to begin to understand the public's attitudes about our program.

3.1.2. Identifying potential donors

To measure public interest in installing solar – identifying our pool of potential donors – we asked if people are "currently considering installing or buying...solar panels?" In our survey, three percent of the national public reported having solar panels installed (Figure C1), which closely matches the 3.7% of households the Energy Information Administration reported having solar in 2020 [53]. While solar ownership is not widespread, 23% of the sample expressed interest in installing solar.

Next, we asked about beliefs regarding inequities in solar adoption. This question serves as the basis to evaluate our hypothesis about inequity aversion in later regression analyses. Fig. 2 shows that the public believes low-income and communities of color have benefited the least from solar, whereas they think high-income earners and energy companies have benefited the most. This ordering reflects actual patterns of solar adoption.

3.1.3. Willingness to donate

Would people donate, and if so, how much? Table 1 shows the sample weighted responses to our question about willingness to pay higher utility bills if the funds went to installing and maintaining solar in low-income communities. Since our population of potential donors are those interested in solar, we break out responses accordingly. There is a substantially greater willingness to pay higher electric bills among those interested in solar than those with little interest.

Table 1
Differences in willingness to pay higher electric bills if the funds help install solar in low-income communities.

	Solar interest	
	No	Yes
Strongly agree	4	17
Somewhat agree	30	45
Somewhat disagree	30	21
Strongly disagree	36	17

Notes: Nationally representative survey ($N = 887$). Respondents were asked how much they agreed with the following statement: "I would pay higher utility bills if the money went to supporting solar panel projects in my community that would reduce energy costs for low-income residents". Chi-squared test for difference in frequencies ($p < 0.001$).

Next, we evaluated whether there is public interest in our proposed program. We find that among the likely participant population, 64% would donate. Fig. 3 shows that the average solar-inclined respondent would donate 37% of her monthly surplus. While those with no interest in solar would contribute less, there remains interest. When looking at expectations of what neighbors would do, which perhaps reduces the effect of "cheap talk", the donation allocation falls modestly. A considerable share would still donate.

Table 2 reports the correlates of donation size from a linear regression of the amount donated on attitudinal and demographic covariates corresponding with our hypotheses. We also include covariates from the public opinion literature on clean energy. The outcome is standardized for interpretation, so a one-unit increase in a covariate represents a one-standard deviation increase in donations.

We find evidence consistent with our hypothesis that the intention to purchase solar panels has a positive correlation with donation size. This pattern holds when controlling for factors that could predict solar purchasing intention, like party identification, income, and rurality.

We also find that greater climate change concern has a positive correlation with donation size. This association appears even when accounting for factors that could predict climate change concern like partisanship. Concern about climate change could drive people to behave more altruistically, perhaps because they are motivated by achieving faster emissions reductions and see solar deployment as a means to achieve that end.

For the inequity aversion hypothesis, there is a positive correlation between believing that the wealthy have benefited from solar and donation size. However, the magnitude of this coefficient is modest. The

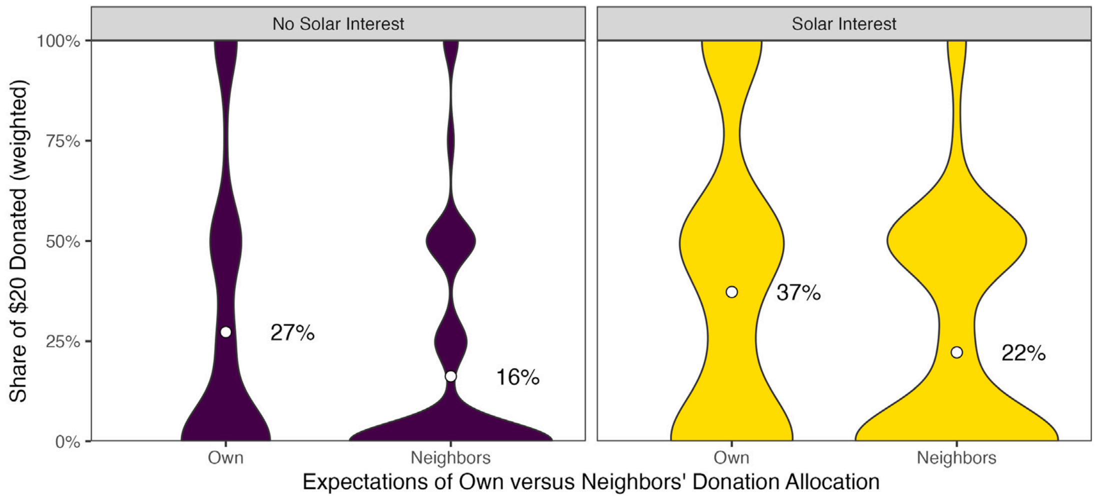

Fig. 3. Allocation of $20 net metering proceeds between donations to low-income communities for solar and keeping the proceeds. The plot shows an individual's own allocation compared to expectations of what one's neighbors would donate. The width of the curve is a density plot, which shows the distribution of responses for a given value. The labeled point represents the average allocation. The data are broken out by whether respondents are not interested in solar (left) or are in the population of potential donors because they already have or are interested (right) ($N = 887$).

correlation also attenuates slightly once controlling for solar interest and climate change beliefs.

Other consistent patterns emerge. As found in the literature on inequity aversion, women make larger donations on average [52]. Surprisingly, there is no correlation between income and donation size. Republicans and Independents also make smaller donations on average than Democrats. These estimates are qualitatively consistent with other measures of partisanship (Appendix B.2.) However, this correlation disappears once the models control for climate change concern.[6]

3.2. Estimating revenue and solar potential

We performed a back-of-the-envelope calculation to estimate the potential impact of our polycentric model if households with solar in 2021 had the option to make solar donations. We used data on electricity prices and net metering from residential solar to calculate the dollar value of net metering in each state. Then, we used our survey data to calculate the average donation people would make in each state, which allowed us to estimate what share of net metering funds in 2021 would have been donated. We present results under increasingly conservative behavioral assumptions about the share of revenue raised. Still, these estimates are biased upward because the price paid for electricity sold back to the grid will be lower than the retail electricity price. We worked to reduce this bias by using fine-grained data at the state and utility level, but we are constrained from characterizing the extent of the mismatch between electricity prices and actual net metering proceeds.

Table 3 reports the results from our calculations of the revenue that could be generated by our program. If contributions matched what individuals said they would give, our program would have raised $83 million in 2021. If they donated in line with what they said their neighbor would give, our program would have raised $47 million. If we take a middle-ground approach that equally weighs one's own donation and expected donation, the program would have raised $65 million.

Using data on the capital costs of residential solar and utility-scale systems with one-axis tracking, we calculate that in our middle allocation scenario the program would have raised enough revenue to install 21,983 kW of solar panels at 3664 homes in 2021. If proceeds were invested in utility-scale solar, it would have been possible to install 65,505 kW of commercial solar power—roughly 66 utility-scale solar farms.

This analysis only intends to provide a proof-of-concept and has important limitations. It holds capital costs constant and abstracts away from general equilibrium effects, which will be important to study. The estimates are also based on a specific survey instrument that reflects a snapshot. Over time, the program could have positive externalities as more people adopt solar, which not only lowers technology costs but could also incentivize donations with the demonstrated success of the program.

3.3. Program design preferences

We also explored how the design of the solar donation program and the institutional context in which it is embedded influences the public's support and willingness to donate funds.[7] We fielded a second national survey of Americans to investigate these questions. In May-June 2023, we collected a sample with Qualtrics.[8] The sample employed nationally representative quotas for age, sex, race, ethnicity, and education. After trimming respondents who failed to pass standard quality controls, the sample totaled 2006 respondents.

3.3.1. Research design

We utilized a methodology called a conjoint to measure preferences over the design of the donation program. This technique works by presenting the survey-taker with a pair of two possible programs. Respondents then select which one they prefer and indicate how much they would donate. For each paired comparison, the programs differed along crucial dimensions, such as the community receiving donations for solar projects. Table 4 describes the program attributes and how they varied. Fig. 4 provides an example of a paired comparison a respondent saw. Crucially, the values of the program attribute were randomized, which avoids potential confounding from individual differences in how people interpret information. This conjoint methodology is a robust and externally valid way to measure multidimensional preferences [54], and has been employed to study preferences over the design of energy and climate policies [55,56].

The first attribute, additional tax credits for donation recipients, examines how the extent of top-down federal support influences willingness for bottom-up donations. Respondents likely interpreted this as

[6] Tobit models addressing censoring reveal similar results.

[7] We pre-registered our hypotheses regarding these experimental interventions with OSF (https://osf.io/wuag5/).

[8] The cost per quality completed response was about $7.

Table 2
Regression of donation to help install and maintain community solar in marginalized communities on individual covariates.

	DV: Donation to install solar (standardized)				
	(1)	(2)	(3)	(4)	(5)
Climate change concern (index)		0.253***			0.221***
		(0.063)			(0.066)
Intend to buy solar			0.281**		0.221*
			(0.125)		(0.130)
Rich benefit from solar				0.094**	0.048
				(0.047)	(0.050)
Woman	0.160	0.147	0.180*	0.172*	0.171*
	(0.101)	(0.100)	(0.103)	(0.101)	(0.103)
Age (standardized)	0.010	0.048	0.029	0.011	0.057
	(0.058)	(0.056)	(0.056)	(0.059)	(0.056)
College degree	−0.014	−0.052	−0.051	−0.032	−0.084
	(0.110)	(0.106)	(0.104)	(0.111)	(0.104)
Rural	−0.023	0.009	−0.035	−0.035	−0.009
	(0.125)	(0.126)	(0.125)	(0.127)	(0.128)
Race (Baseline: White)					
Black	0.046	0.070	0.056	0.068	0.087
	(0.148)	(0.141)	(0.146)	(0.147)	(0.139)
Hispanic	0.185	0.271	0.198	0.203	0.280
	(0.179)	(0.180)	(0.172)	(0.184)	(0.177)
Other	0.088	0.121	0.110	0.091	0.138
	(0.200)	(0.201)	(0.203)	(0.195)	(0.202)
Income (Baseline: $60,000–99,999)					
Less than $29,999	−0.086	−0.133	−0.064	−0.063	−0.100
	(0.155)	(0.153)	(0.154)	(0.155)	(0.153)
$30,000–59,999	−0.203*	−0.230*	−0.180	−0.188	−0.201
	(0.122)	(0.121)	(0.126)	(0.122)	(0.127)
$100,000 or more	−0.060	−0.061	−0.047	−0.045	−0.044
	(0.133)	(0.129)	(0.133)	(0.131)	(0.131)
Prefer not to say	0.075	0.104	0.109	0.093	0.137
	(0.273)	(0.264)	(0.267)	(0.273)	(0.262)
Party (Baseline: Democrat)					
Neither	−0.494***	−0.301**	−0.470***	−0.458***	−0.286**
	(0.130)	(0.137)	(0.128)	(0.130)	(0.132)
Republican	−0.515***	−0.125	−0.490***	−0.474***	−0.135
	(0.128)	(0.174)	(0.128)	(0.130)	(0.174)
(Intercept)	0.265*	0.108	0.162	0.227	0.027
	(0.153)	(0.150)	(0.173)	(0.152)	(0.165)
N	887	882	887	887	882
Adjusted R^2	0.067	0.097	0.081	0.074	0.107
Donation average	6.032	6.032	6.032	6.032	6.032
Donation standard deviation	7.227	7.227	7.227	7.227	7.227

Notes: HC3 standard errors reported. Regressions employ survey weights.
* p < 0.1.
** p < 0.05.
*** p < 0.01.

Table 3
Estimated revenue-raising potential under allocation scenarios and implications for scale development.

Allocation measure	Revenue	Residential		Utility	
		kW	Homes	kW	Farms
Own donations	$82,932,862	28 113	4685	83 771	84
Own (50%) + neighbor (50%) donations	$64,850,371	21 983	3664	65 505	66
Neighbor donations	$46,767,880	15 854	2642	47 240	47
Neighbor donations (discounted 50%)	$23,383,940	7 927	1321	23 620	24

Notes: The row at the bottom discounts the neighbor's donation by 50% to present an extreme scenario to show that the program would still raise revenue even if there were upward bias. These estimates could be further scaled down at varying degrees based on the gap between electricity prices and the price of electricity sold back to the grid, which varies by state and utility. Home and farm estimates assume a 6-kilowatt average residential solar project and a 1-megawatt average utility-scale project. Appendix D describes our methodology.

a federal tax credit because it accompanied the "Federal Tax Credit for Solar Installation" attribute. Specifically, we varied whether the government provides additional tax credits for the donation recipient. We were agnostic about the effect of this attribute because, on the one hand, one could imagine a substitution effect where top-down involvement crowds out donations. On the other hand, people could see complementarities, thinking their money would go further.

The second attribute, federal tax credit for solar installation, further explores the potential for top-down versus bottom-up trade-offs by varying the size of federal tax credits for solar installation. The precise values of the federal tax credit match the phase-down schedule of the residential solar tax credit as enacted by the IRA, which allows for an initial assessment of how donations might change in response to the IRA's implementation.

The third attribute, the target community, examines whether the group that receives donations makes a difference in program participation and donation amount. The values range from any community

Table 4
Conjoint attributes and levels.

Attribute	Levels
Additional Tax Credits for Donation Recipient	None 10% tax credit
Federal Tax Credit for Solar Installation	0% 22% 26% 30%
Target Community	Any Rural Low-income Coal, oil, and gas producing Black, Brown, and Indigenous
Community Member Participation	0% 10% 20% 30%
Solar Project Type	Local businesses Solar field for entire community Schools Places of worship/community centers Individual households
Your Average Solar Yearly Profits	\$300 \$500 \$700 \$900

to specific types of communities such as rural, low-income, or Black, Brown, and Indigenous.

The fourth attribute, community member participation, randomized the share of people with rooftop solar who participate in the program. As discussed above, behavioral psychology research suggests that greater participation creates social pressure to take part and donate more [45,46].

The fifth attribute varied the type of solar project to see if the target within a given community affected interest in participating and donation amount. The levels of this attribute differed in terms of whether the target was a private entity, such as a local business, individual household, or place of worship, or public, such as a solar field for the entire community or schools.

The last attribute, the average yearly profits, examines the effect of larger net metering proceeds on the generosity of program participants' donations. This attribute assesses whether people become more generous if they have more proceeds, which might reduce the budgetary trade-offs they could face when donating the surplus.

We took several steps to enhance respondent comprehension since the experiment asked the survey-taker to consider many dimensions, which might be cognitively intensive. First, we provided clear instructions and an example of the conjoint table. On the same page, we asked a series of true or false questions about the conjoint, which encouraged the respondents to read carefully. If someone answered these questions incorrectly, they would be shown the answers to ensure comprehension. When analyzing the responses conditional on the level of comprehension, we find qualitatively consistent preferences.[9]

To analyze the conjoint experiment, we used a linear regression model to estimate the public's preferences over the design of the solar donation program. There are two outcomes. The first is a binary indicator variable for whether a respondent selected a program. The second outcome is the percent of a respondent's yearly net metering proceeds she would donate under each program. Since we examine the same respondent's choices across four paired comparisons, we cluster standard errors at the individual level.

3.3.2. Results

Fig. 5 shows the effect of a change in an attribute's level from the baseline on the probability of selecting a solar donation program. Beginning with attributes capturing the interplay of top-down and bottom-up design elements, we find no trade-off between federal action and bottom-up efforts. On the contrary, when the federal government provides additional tax credits for the donation recipient and more generous tax credits for solar installation, support for the donation program rises.

The target community to receive donations also makes a difference. Directing funds to low-income communities increases public support by 5% compared to the baseline of all communities being eligible for donations, whereas targeting fossil fuel communities and Black, Brown, and Indigenous communities lowers support for the solar program on average.

Within a community, the target of a project makes a difference. There is greater support for projects that provide broad local benefits such as community solar projects and panels on schools. There is also greater support for projects on individual households but not for local businesses and places of worship.

Lastly, there is a roughly linear increase in support as an individual's average solar net metering proceeds rise. In other words, as people make more money from participating, they become more likely to prefer the program.

The results are qualitatively similar when the outcome variable is the amount one would donate rather than the choice outcome (Fig. 6). An advantage of examining donation outcomes is the results provide a monetary estimate of the impact of design features. Having the funds go to community solar projects causes the largest increase in donations: 3% more a month compared to a program that targeted local businesses. By contrast, a solar program that targeted fossil fuel communities would lead to 2% fewer donations compared to the baseline of any community being eligible to receive donations.

We also explored whether these preferences differed for Democrats, Republicans, and Independents (Appendix F.2). We find that preferences generally converge across partisans. However, Democrats respond more strongly to community member participation than Republicans. Republicans are less likely to support having the program target Black, Brown, and Indigenous communities, a 15% decline in the probability of supporting a program, whereas Democrats and Independents are indifferent. These patterns are consistent with public opinion on welfare policy [57].

Following the conjoint experiment, we asked respondents to rank the attributes from most to least important to see what program design features made the biggest difference in their evaluations. The target community was consistently ranked as the most important attribute (Figure F4).

We also asked individuals to rank their preferred target community. There is overwhelming support for targeting low-income communities (Figure F5). This indicates a clear preference for a targeted approach to donations, directing the funds to the places where they will have the most impact.

3.4. Effect of polycentric governance

A theoretical motivation for our polycentric model is that top-down efforts confront hurdles that could be avoided by bottom-up action that leverages multiple levels of governance and organization. We conducted a survey experiment to evaluate this claim, which is necessary to see if people would support a polycentric program—willingness to participate is a prerequisite to piloting our model in the real world.

The experiment varied whether the donation program was overseen by the state government, the local electric power company, or the two working together with communities. The last condition represents polycentric governance with multiple levels of actors engaged in a common problem. Appendix H.1 contains the instrumentation.

[9] People with higher comprehension are slightly more supportive of programs with higher average net metering proceeds, those that target low-income communities, and greater community member participation.

Round 1

Please read the descriptions of the two programs carefully. Then pick which one you like best and say how much of your profit from solar you would choose to donate under each program.

	Program A	Program B
Additional Tax Credits for Donation Recipient	None	10% tax credit
Federal Tax Credit for Solar Installation	0%	22%
Target Community	Any	Low-income
Community Member Participation	10%	30%
Solar Project Type	Solar field for entire community	Individual households
Your Average Solar Yearly Profits	$500	$900

Which program do you prefer?

- ○ Program A
- ○ Program B

What percent (from 0 to 100) of your yearly solar profits would you choose to donate under each program?

Program A

Program B

Fig. 4. Example of conjoint task from respondent's perspective.

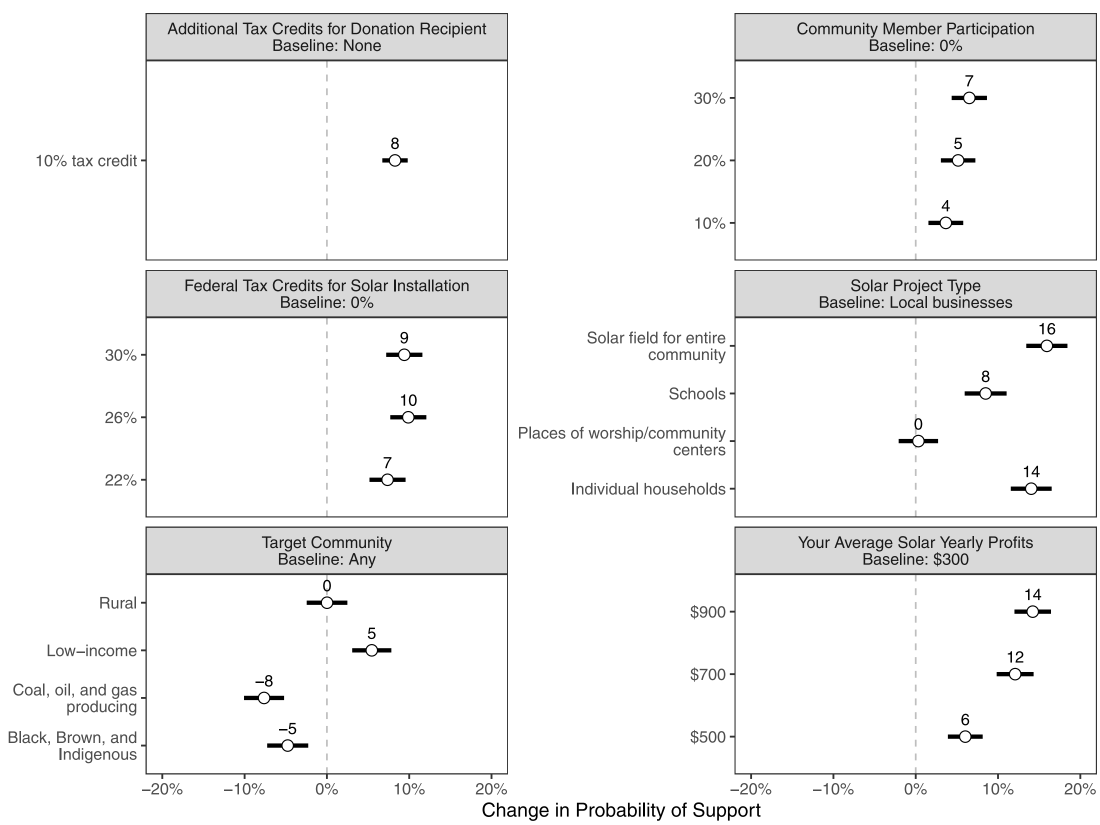

Fig. 5. Average change in probability of selecting a solar program depending on the program design. Bars denote 95% confidence intervals with robust standard errors clustered by respondent. 16,048 program comparisons made by 2006 national respondents.

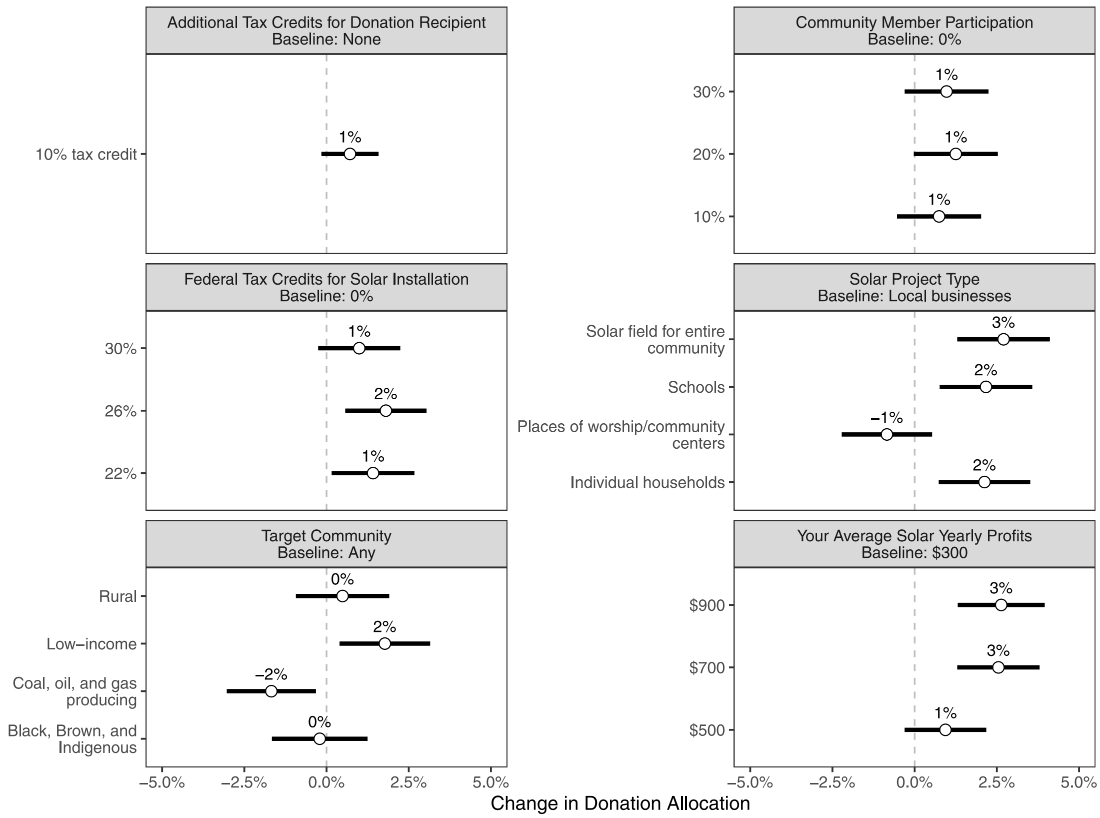

Fig. 6. Average change in donation allocation depending on program design. Bars denote 95% confidence intervals with robust standard errors clustered by respondent. 16,048 donation allocations made by 2006 national respondents.

We evaluated a range of outcomes, including expectations of how successful the program would be at encouraging people to sign up, helping the community targeted for donations, and deploying solar. We expected polycentric governance would increase perceptions of the program's success. Additional questions probed whether polycentric governance affects the legitimacy of changes to the eligible communities to receive donations and other program rules.

Fig. 7 presents the causal effects of the polycentric governance and local power company treatments, compared to the control condition where the state government is in charge. Polycentric governance causes the largest increase in beliefs about how successful the program would be across all dimensions. There is no effect on beliefs about the legitimacy of a change in the program's rules, which is likely because people may need more information to evaluate the acceptability of such a change. The power company treatment, compared to the state government acting alone, has a weaker but positive effect on expectations of program success. Together, these results indicate how the public has greater faith in polycentric solutions.

We randomly assigned half of the respondents to write open-ended responses elaborating on their answers about expectations of the program's success in encouraging participation. We analyzed these responses using a structural topic model [58]. The most frequently mentioned topic is the desire to help others, followed by the financial incentive to save money from solar. We also find that people in the polycentric treatment group are less likely to mention concerns about government involvement and may be more likely to mention benefits like savings and environmental improvement (Table H1).

The other half of the respondents were randomly assigned to write an open-ended response elaborating on their belief about how effective the program would be in helping low-income communities. The results show that the most frequent topic is that the program would be successful, followed by concerns about solar's affordability. People in the polycentric treatment group were less likely to mention concerns about the government being slow or untrustworthy but were more likely to mention worries about the power company being a barrier (Table H2).

3.5. Countering loss aversion

We also conducted an experiment to evaluate how the program could be designed to minimize loss aversion. As discussed above, loss aversion could impede program participation. This concern arose in discussions we had with colleagues and a solar installation company in the spring of 2023. Here, loss aversion is around the expectation of future losses, which differs from standard models of loss aversion that are present-based. As a solution, we considered a credit bank, where donations would occur from net metering proceeds only after reaching a certain threshold, so an individual would never be in the domain of losses. Importantly, this does not guarantee overall profits once taking into account installation costs, so costs were likely salient for survey-takers. In the experiment, we randomized whether the donation program had a mechanism to protect against losses (Appendix G.1). Since people may not be interested in the details of proposals, the intervention emphasized that the program would be set up so they would not have to pay out of pocket for electric bills. If people doubted the solution's feasibility, they would underestimate the potential of our proposed credit bank.

Our outcomes measured how much one would donate and the expectations of donations by one's neighbors. We also assessed whether people would be interested in participating, seek information about the program, and share information with their friends and family. Lastly, we measured how much the public would support having their power company offer the program. We anticipated that designing the program to minimize losses would increase donations, participation, information seeking and sharing, and program support.

We used a linear regression model to estimate the causal effect of the protection against loss treatment on these outcomes. The model

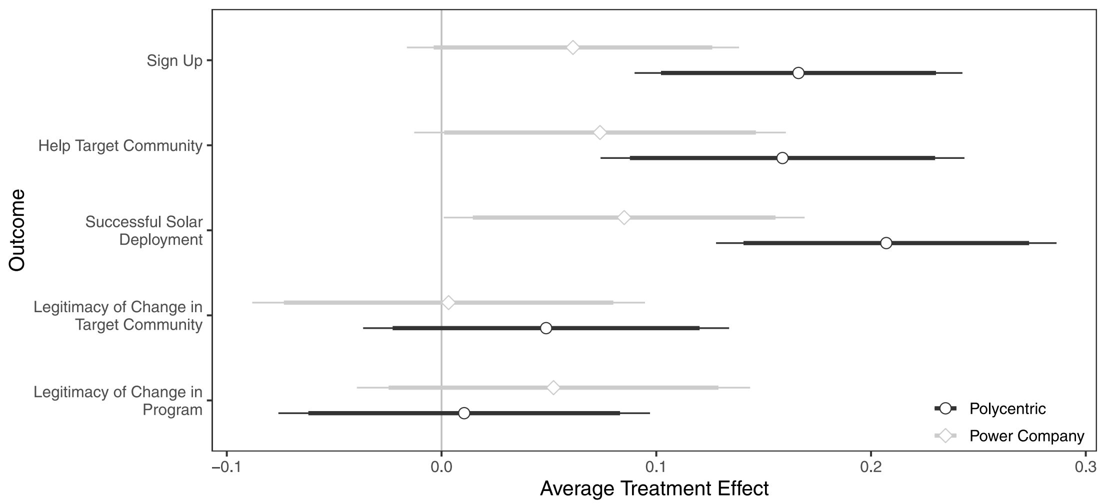

Fig. 7. Average effect of polycentric and power company treatments compared to the control condition of state government implementation on outcomes related to the success and legitimacy of the solar program. Bars denote 90 and 95% confidence intervals with HC2 standard errors. $N = 2006$.

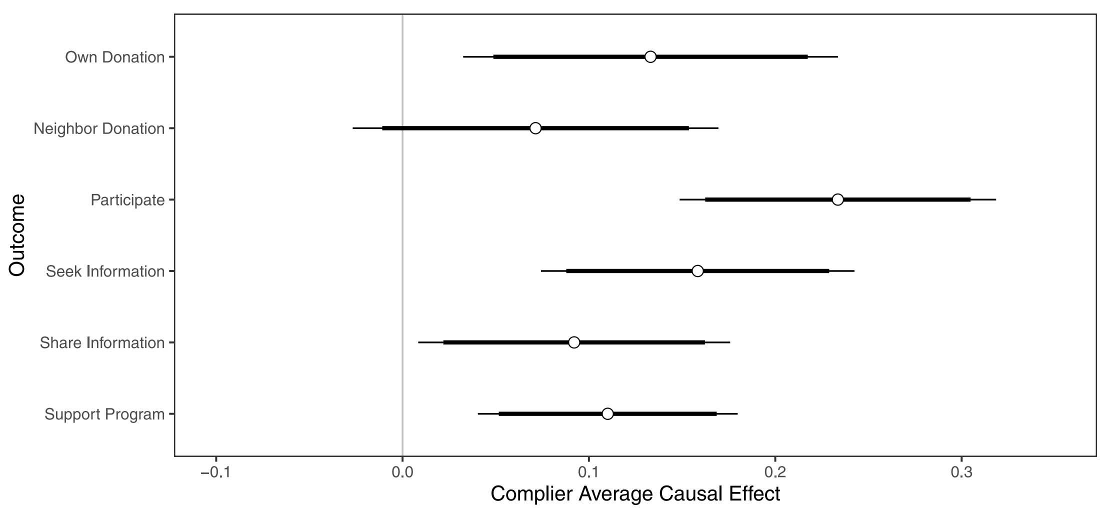

Fig. 8. Effects of protections against losses in solar program. Bars denote 90 and 95% confidence intervals with HC2 standard errors. $N = 1589$.

includes covariates predictive of these outcomes to improve efficiency. Since the intervention was nuanced, the analysis examines individuals who complied with the treatment, as measured by a post-treatment question about whether one would be concerned about paying out-of-pocket for electric bills. While this approach allows for more internally valid estimation of the treatment effects, it introduces additional considerations for external validity. People who were more likely to defy the treatment tended to be women, thought their home was not suitable for solar or were less trusting. The treatment may be less likely to generalize to these groups, which points to new avenues for research to identify targeted solutions.

Fig. 8 presents the results from estimating the effect of the loss aversion solution on the outcomes. Designing the program to protect against losses matters: people would make larger donations, be more likely to participate, seek and share information, and support their power company adopting the initiative. For the question where one adopts the perspective of her neighbor, the coefficient is positive, but the bottom of the confidence interval touches zero. If this is an indication of social desirability bias, it might suggest that protection against losses is not as important for the amount that people donate. However, moving people from the domain of losses to gains makes a robust, positive difference in program participation and support, which matters for growing a base of donors.

3.6. *Effect of flywheel design*

An advantage of our program is that it could create a virtuous flywheel. This idea refers to how communities receiving donations to build solar projects also generate surplus net metering proceeds that could be used for new solar development in other communities. In turn, this process generates positive spillovers—hence, the virtuous flywheel.[10]

We conducted a survey experiment to see whether emphasizing this flywheel effect would increase program participation. Appendix I.1 describes the survey instrument. The expectation was that if people recognized how their money could have positive, compounding effects, they would be more willing to support the program.

Table I1 reports the results of estimating the effect of a message emphasizing the flywheel benefits on support for the program. The treatment causes a large increase in program support. When analyzing differences in the treatment's effects across relevant subgroups, there is little heterogeneity, save for a stronger positive effect of the treatment among more altruistic individuals—the potential donor pool.

[10] The metaphor of a flywheel is distinct from policy feedback effects.

3.7. Attitudes about power companies

Power companies confront public relations challenges and some have resisted net-metering [22]. This suggests that one incentive for power companies to offer our program is that it could help foster a good reputation in the communities they serve. In many locations, it will be necessary to work with the local utility to install solar and facilitate the proposed program, so implementation may depend on collaboration with utilities.

We used a survey experiment to evaluate whether our program would offer power companies the opportunity to build goodwill. The experiment described in Appendix J.1 randomized whether the respondent's power company offered our donation program. Then, we asked how favorably one evaluated her power company and how much the power company cared about its community.

We find that offering the solar donation program increases favorable evaluations of power companies. The size of the increase is about a 0.3 shift along a four-point scale, which is appreciable. This boost to favorability happens across individuals with varied trust in government and is even larger for those interested in installing solar (Table J1).

4. Conclusion

We proposed and studied new ways that individuals and organizations could facilitate the deployment of affordable, clean electricity for communities that historically have faced energy poverty. While government programs are trying to achieve similar goals, we examined a ground-up approach that complements top-down programs where they exist and can catalyze action where it has been lacking. Our project builds on efforts to envision how renewable energy could democratize energy development [59].

Our surveys of the American public provide proof-of-concept evidence for our program. To highlight three findings, we first show that a majority of Americans (60%) would be willing to participate, and their donations could raise substantial capital to build out renewable energy for eligible communities. Second, our experiments show how the program can be designed to increase the size of donations by having the funds target low-income communities, complementing top-down subsidies with our bottom-up model, and structuring the program to minimize loss aversion. Third, we provide experimental evidence that the polycentric approach of involving multiple decision-makers increases the perceived effectiveness of the program more so than when the government acts alone.

These results should inspire future research about how our model could be implemented. Follow-on studies could examine larger or smaller budget amounts, whereas we fixed the net-metering proceeds amount to $20 to avoid overestimating how much a household might earn. Tax incentive design provides another avenue of research, such as whether to count contributions as tax-deductible charitable donations or to have states and the federal government provide special tax treatment. There are also additional strategies to motivate participation, such as matching by governments or philanthropic organizations and "challenge" schemes [60,61]. Finally, our model opens the possibility of donating the net-metering proceeds to objectives beyond solar, such as investments to address food insecurity.

Our effort to reimagine how net metering proceeds could be leveraged to achieve social and climate goals takes place against the backdrop of broader debates about the future of the electrical grid. As seen in recent policy developments in California, there is considerable contestation over net-metering and cross-subsidization, rate setting (e.g., differential charges by income level, time-of-day pricing), and incentives for coupling solar with storage. Our proposal aims to operate within the existing constraints of net-metering regimes to achieve social and climate objectives, but one could envision how more fundamental changes to the energy system could also provide complementary paths to reducing inequities in solar adoption.

One next step will be to take our ground-up model into real-world settings. This will require partnering with communities, firms, and governments, which should have incentives to do so because of the program's potential to address energy insecurity and climate change, along with the reputational benefits to the participants. As the program is implemented, it will be important to pay attention to unforeseen challenges that could arise, such as the local economic benefits from the projects or inefficiencies and mistakes [18]. By moving beyond the sole focus on top-down initiatives, our ground-up model hopes to provide a path forward for durable solutions that reduce energy insecurity and address the climate crisis.

CRediT authorship contribution statement

Alexander F. Gazmararian: Writing – original draft. **Dustin Tingley:** Writing – original draft.

Declaration of competing interest

No conflicts of interest to share.

Data availability

The data and code to replicate our results will be made available on the Harvard Dataverse.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.erss.2023.103374.

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